Journal of Coastal Life Medicine

journal homepage: www.jclmm.com

Document heading doi:10.12980/JCLM.3.2015JCLM-2014-0097

Algal massive growth in relation to water quality and salinity at Damietta, north of Egypt

Mohamed Ali Ibraheem Deyab*, Taha Mohamed El-Katony

Botany Department, Faculty of Science, Damietta University, New Damietta City, Egypt

PEER REVIEW

Peer reviewer

Dr. Zakaria A. Mohamed, Professor of Aquatic Toxicology/Algal Toxins, Faculty of Science, Botany Department, Sohag Univeristy.
E-mail: mzakaria_99@yahoo.com

Comments

The authors gathered valuable data stating the current status of Damietta Mediterranean coastal waters in terms of eutrophication and algal blooms. On the other hand, the study demonstrated that some of these algal species are rich in proteins and nutritional elements.
Details on Page 120

ABSTRACT

Objective: To relate the proliferation and dominance of certain algal species at the Damietta and its relation to water quality.
Methods: Water and algal biomass were bimonthly sampled from five selected sites at Damietta Province, Egypt during 2012. Algae were identified and quantified. Waters, algae and sediment were analyzed.
Results: The physicochemical properties of water showed limited seasonal but substantial local variation. The high levels of nitrogen and phosphorus and turbidity of water pointed to marked eutrophication, which could enhance massive algal growth. The temporal fluctuation in temperature, exposure to industrial and domestic sewage and salinity results in succession between blooming algal species. *Spirulina platensis* and *Chlorella vulgaris* alternated in a moderately saline water and *Oscillatoria agardhii* and *Mougeotia scalaris* in a fresh water body during summer and winter respectively. Likewise, *Microcystis aureginosa* and *Ulva lactuca* alternated in a moderately saline site during autumn and summer respectively. *Cladophora albida* dominated a fish pond of brackish water and *Dunaliella salina* dominated the most saline water over the whole period of study.
Conclusions: Growth of the predominant algal species is correlated to water quality. These species are of considerable nutritive value, with moderate contents of protein, carbohydrate, macronutrients and micronutrients, which evaluates them for usage as food (green and macroalgae), fodder or bio-fertilizer (cyanophytes).

KEYWORDS

Algal growth, Water quality, Sediment, North Damietta, Egypt, Waste water treatment, Algal succession

1. Introduction

The environmental conditions of the aquatic ecosystems in the north of Egypt, particularly in Damietta Province, are quite suitable for the development of massive algal blooming, thus leading to water pollution and imposing serious threats to the aquatic organisms and quality of water. In this context, increasing water turbidity and cyanobacterial blooming have been reported to be the causative agents of gastrointestinal illness[1]. In addition, the continuous discharge of agricultural and domestic effluents into the shallow waters prevailing therein might aggravate the problem through over-enrichment with nutrients, in particular nitrogen and phosphorus.

Blooming of algal species exhibits a wide range of ecological niches. For example, high salinity levels favor blooming of *Dunaliella* species[2] and the golden alga *Prymnesium parvum*[3]. By contrast, higher salinity suppresses the blooming of *Scenedesmus* spp. as they are freshwater organisms[4]. Furthermore, the bloom forming cyanophytes can tolerate harsh environments and flourish under stress conditions. *Oscillatoria* species can tolerate or even adapt to low oxygen concentrations and high light intensities[5]. Abundance and proliferation of *Cladophora* spp. are often associated with changes in phosphorus availability[6].

Despite they are serious impacts on human health and the

*Corresponding author: Mohamed Ali Ibraheem Deyab, Botany Department, Faculty of Science, Damietta University, New Damietta City, Egypt.
Tel: +002-057403866
Fax: +002-057403868
E-mail: modeyab@yahoo.com

Article history:
Received 28 Jul 2014
Received in revised form 17 Aug, 2nd revised form 28 Oct 2014
Accepted 2 Nov 2014
Available online 8 Nov 2014

aquatic environments, the blooming of cyanobacteria can afford several benefits. *Spirulina platensis* (*S. platensis*), for example, is promising as a potential source of protein[7], with anticancer and antiviral activities, particularly against HIV virus[8]. In addition, the alga has a prominent anti-inflammatory and antioxidant properties due to the high content of phycocyanin[9]. *Oscillatoria redekei* also exhibited antimicrobial activity against a wide range of pathogenic bacteria[10]. Other non-cyanobacterial blooming species such as *Dunaliella salina* (*D. salina*) can be utilized for production of both protein and the antioxidant pigment β-carotene[2]. Because of their high productivity in eutrophic waters, *Spirulina* species have been exploited to remove nutrients and heavy metals from the anaerobic pig waste water under tropical conditions[11].

The present study was carried out to characterize the problem of massive growth of algae at the north of Damietta, Egypt and its relation to water quality, and also to search if there is a probable benefit can be afforded by this phenomenon.

2. Materials and methods

2.1. The study area

Five sites were selected along the Mediterranean coast of Egypt in Damietta Province (Figure 1) to study the phenomenon of massive algal growth. These sites were west El-Deepa (Site I), EL-Basailla (Site II), New Damietta fish farm (Site III), a military base-pond (Site IV) and Abu El-Ross (Site V). These sites reflect variation in the geomorphology and the exposure to agricultural and domestic sewage.

Figure 1. A map of the study area showing the sampling sites.
Site I: El-Deepa; Site II: EL-Basailla; Site III: New Damietta fish farm; Site IV: A military base-pond; Site V: Abu El-Ross.

2.2. Sampling and analysis

Samples of surface water and algal growths were bimonthly collected from aforementioned sites over a period of one year, and samples of sediment were collected once in November. Water temperature and turbidity (using a turbidity meter) were measured *in situ*. Water turbidity was measured using a 2008 Lamotte turbidity meter. Samples were transported in an icebox investigated within few hours after collection. Water chemistry analyses, included determination of salinity, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, NO_2^-, NO_3^-, total nitrogen (N), total phosphorus (P), $H_2PO_4^-$, Zn, and Fe were conducted according to Jackson[12] and American Public Health Association[13]. Sediment samples were collected from the bottom of the studied sites and brought to the laboratory in plastic bags, spread over large glass plates, air-dried, thoroughly mixed, and passed through 2 mm sieve to remove gravel and debris. Sediment-water extract in a ratio of 1:5 was prepared for determination of pH, the levels of salinity (estimated as EC) and available cations and anions. In addition, the contents of calcium carbonate, organic carbon, total N and total P were determined in the air-dried sediment.

Algal species were identified according to Sladká and Sládeček[14]. The Sedgwich-Rafter counting chamber was adopted for quantitative analysis of microalgae. Algal biomass was determined as biovolume by multiplying the average volume of water by the number of organisms per mL using the appropriate geometric formula[15]. During the period of massive growth of bloom forming algae, biomass was measured as fresh weight: for most microalgae as g/L fresh weight and for macroalgal species as kg/m^2 fresh weight.

Algal species, both macro- and microalgae, were collected during their maximum growth period and the macroalgae were carefully rinsed with distilled water to remove epiphytes and calcareous deposits, and oven dried at 60 ˚C for 24 h. Protein content was determined according to the method of Lowry *et al*[16]. Total carbohydrates were determined according to the method of Herbert *et al*[17]. Chlorophylls were determined according to the method described by Talling and Driver[18].

A portion of the dried powdered algal biomass was ashed at 400 °C for 6 h in a muffle furnace. Organic matter (OM) was estimated as the loss in weight by ignition and organic carbon (OC) by calculation. Another aliquot of the algal biomass was digested with the H_2O_2/sulfuric acid method and the contents of total P and total N were determined according to the methods adopted by Allen *et al*[19]. K content was determined by using a Jenway PFP7 flame photometer. The contents of Fe, Zn, Mn, Pb and Cu were determined by using a Pye Unicam SP 90 atomic absorption spectrophotometer.

2.3. Statistical analyses

Analysis of variance (ANOVA) and correlation analysis (Pearson correlation coefficient two-tailed) were performed by using SPSS (version 22) program. Means were separated according to the Duncan's multiple range test at $P \leqslant 0.05$.

3. Results

3.1. Water characteristics

Water temperature exhibited a limited (non-significant) variability among the different sites of study (P=0.06), but the seasonal variability was expected with a minimum of 10.8 ˚C during January and a maximum of 29.0 °C during July (Table 1). By contrast, water turbidity showed marked local variability but limited seasonal variability. Out of the five sites investigated, only Site V (the least saline site) showed also the least turbidity (an annual average of 3.35 NTU); and the remaining four sites being highly turbid, particularly Site IV (the most saline site) with an annual average

Table 1
Physicochemical properties of water samples taken bimonthly from the study sites.

Site	Month	Temp (°C)	Turbidity (NTU)	pH	Salinity (g/L)	COD (g/L)	DO (mg/L)	BOD (mg/L)	NH_4^+-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	Total N (mg/L)	Orthophosphate (mg/L)	Total P (mg/L)	Zn (mg/L)	Fe (mg/L)
I	Jan	10.8	131.0	7.85	41.4	0.65	3.80	18.00	1.60	1.10	0.30	27.00	1.70	2.30	1.70	0.09
	Mar	20.0	130.0	7.99	30.5	0.44	2.80	28.00	1.30	1.20	1.10	24.00	1.40	3.10	3.60	0.40
	May	23.0	133.0	8.70	45.1	0.81	0.50	70.00	4.70	1.70	2.80	35.00	1.90	3.80	4.90	0.71
	Jul	29.0	140.0	9.15	54.5	0.56	2.20	32.00	1.30	0.10	0.80	17.00	1.90	4.80	3.10	0.50
	Sep	27.5	138.0	8.95	49.4	0.71	1.50	38.00	1.10	0.10	0.50	16.00	1.80	4.20	3.50	0.42
	Nov	24.0	141.0	8.11	38.8	0.65	2.60	25.00	1.70	0.10	0.80	11.00	1.20	4.10	1.80	0.22
II	Jan	11.0	96.0	8.14	45.2	0.88	6.00	9.50	1.11	0.42	0.19	12.30	0.07	0.43	0.04	0.01
	Mar	21.0	122.0	7.90	44.7	0.70	6.42	6.00	1.20	0.25	0.45	14.30	0.05	0.39	0.06	0.01
	May	24.0	141.0	8.10	48.9	0.83	6.80	6.40	0.83	0.20	0.32	09.34	0.77	2.60	0.07	0.03
	Jul	29.2	121.0	8.14	51.3	0.94	6.00	6.05	0.62	0.14	0.42	08.60	1.06	3.30	0.10	0.06
	Sep	28.0	136.0	8.46	49.2	0.99	5.33	5.00	0.51	0.15	0.23	7.78	1.67	3.90	0.09	0.04
	Nov	24.2	141.0	8.35	61.4	1.04	4.94	13.80	1.83	0.64	0.95	46.10	1.20	2.80	0.13	0.08
III	Jan	11.0	122.0	7.80	19.0	0.20	7.30	4.20	0.50	0.10	0.20	4.10	0.40	2.10	0.20	0.06
	Mar	21.0	131.0	7.50	23.0	0.40	6.20	5.20	0.20	0.10	0.10	5.30	0.80	2.80	0.30	0.03
	May	24.0	102.0	8.20	25.0	0.40	6.40	5.10	0.10	0.10	0.10	4.20	0.40	3.10	0.10	0.06
	Jul	30.0	131.0	8.70	30.0	0.30	2.70	23.00	0.30	0.10	0.20	8.60	0.80	3.80	0.10	0.04
	Sep	28.0	136.0	8.90	15.0	0.50	3.10	15.00	0.20	0.10	0.10	9.90	0.90	4.60	0.10	0.03
	Nov	25.0	141.0	8.50	24.0	0.30	2.30	27.00	0.50	0.20	0.30	19.00	0.90	3.80	0.10	0.05
IV	Jan	10.0	144.0	7.50	68.0	0.90	2.10	25.00	0.10	0.10	0.10	20.00	0.70	2.90	1.30	0.10
	Mar	21.0	145.0	7.70	60.0	0.70	3.70	13.00	0.20	0.30	0.10	17.00	0.40	3.30	0.70	0.09
	May	23.0	142.0	8.20	65.0	0.70	2.70	19.00	0.20	0.20	0.10	11.00	0.60	4.10	0.80	0.10
	Jul	29.0	148.0	7.80	71.0	1.10	1.20	46.00	0.40	0.40	0.30	6.30	0.90	4.50	0.90	0.08
	Sep	27.0	144.0	7.70	61.0	0.90	2.30	23.00	0.30	0.10	0.10	8.50	0.90	4.40	1.20	0.08
	Nov	24.0	146.0	7.60	65.0	1.10	1.20	47.00	0.10	0.10	1.10	25.00	0.80	3.20	1.40	0.10
V	Jan	11.0	3.6	7.70	1.5	0.20	7.10	4.50	0.50	0.10	0.90	13.00	0.80	2.40	1.80	0.10
	Mar	20.0	3.1	8.20	2.5	0.40	3.50	13.00	0.40	0.20	0.90	19.00	1.80	3.10	2.40	0.09
	May	24.0	2.9	8.30	2.7	0.30	5.80	8.00	0.30	0.10	0.60	13.00	1.20	6.80	2.20	0.08
	Jul	28.0	3.8	8.50	3.6	0.30	4.50	9.40	0.50	0.20	0.80	15.00	1.30	5.10	2.30	0.10
	Sep	27.0	3.4	8.10	2.3	0.30	3.10	12.00	0.20	0.30	0.80	15.00	1.40	4.60	2.40	0.10
	Nov	24.0	3.3	7.90	2.4	0.30	6.10	7.30	0.40	0.10	0.50	5.70	0.60	3.50	2.10	0.10

turbidity of 144.83 TNU.

The pH values of the water were slightly alkaline (⩾7.5) and showed significant local and seasonal variability. The pH was relatively high during summer particularly at Site I (9.15) and low during winter particularly at Site IV (7.50) (Table 1).

The other ecological parameters of the water showed great variability but a non-significant seasonal variability (Table 1). Water salinity varied from about twice the sea water level (an annual average of 65.0 g/L) at Site IV to that of fresh water (an annual average of 2.5 g/L) at Site V. Although the seasonal variability was non-significant, a clear trend was evident with a peak of 42.0 g/L in July and a minimum of 35.0 g/L in January, as an average of all sites. In addition, this seasonal fluctuation was rather limited at the most saline site (Site IV) but was relatively high at the least saline site (Site V).

Site I showed the highest orthophosphate content with an annual average of 1.65 mg/L and a maximum of 1.91 mg/L in May-July, while Sites III and IV was the least, with an annual average of 0.71 mg/L and a minimum of 0.40 mg/L in January and March. Seasonally, orthophosphate was relatively high (0.7-1.87 mg/L) during the period from May to November and low (0.44-1.43 mg/L) from November to March. The local variability in orthophosphate concentration was remarkably high during January-March and low during September-November. Total P followed somewhat the same pattern.

The DO content was relatively high at Sites II, III and V (5.20 mg/L in average) particularly in January, but relatively low at sites I and IV (2.22 mg/L in average) particularly in May and November. The local variability was relatively high (about 13.60-fold) in May but low (about 2.29-fold) in March. By contrast, the BOD showed a maximum of 70.00 mg/L at Site I in May and a minimum of 4.20 mg/L at site III in January. The BOD was in general higher at Sites I and IV (with an average of 32.00 mg/L) than the other sites (an average of 10.03 mg/L). The local variability in BOD was distinctly high (about 13.72-fold) in May. Despite the low seasonal variability in BOD, there was a trend of high levels during the period from May to November relative to the other periods. COD, the highest among the oxygen fractions, showed a high annual average of 0.90 mg/L at Site IV with a peak of 1.10 mg/L in November and a low average of 0.32 mg/L at Sites III and V with a minimum of 0.20 mg/L in January.

The levels of ammonia, nitrite and nitrate were the highest (an annual average of 1.95, 0.72 and 1.05 mg/L respectively) at Site I with peaks of 4.65, 1.65 and 2.80 mg/L respectively in May. The lowest levels of ammonia and nitrite were found at Site IV with an annual average of 0.22 and 0.20 mg/L respectively, while the minimum of nitrate (0.17 mg/L) was at Site III. The local variability in ammonia was substantial in May (about 47-fold) and relatively weak (just 4.33-fold) in July, while that of nitrite and nitrate was relatively high during January-May (about 13.33 and 16.00-fold

respectively) and extremely limited during July-November (only 4.47 and 5.22-fold respectively).

The contents of Zn and Fe were the highest at Site I with an annual average of 3.10 and 0.39 mg/L respectively with peaks of 4.9 mg/L and 0.71 mg/L respectively in May, and the lowest (0.01 mg/L as an average of the two elements) at Site III in January. The local variability in Zn was in general high, but it was particularly substantial (about three orders of magnitude) in the period from January to May and relatively weak (two orders of magnitude) in the period from July to November. The local variability of Fe was less evident than in the case of Zn, with a peak of 40-fold in March and a minimum of 4.4-fold in November. Despite the limited seasonal variability, the concentrations of Zn and Fe exhibited distinct high levels during the period from March to September and low levels during November to January.

Table 2 summarizes the relationship between the different characteristics of water at the study sites. The data revealed that water turbidity was positively correlated with water salinity, COD and BOD, but negatively correlated with DO. Water pH was positively correlated with orthophosphate, total P and Fe. The different oxygen fractions were positively correlated with water salinity. COD was positively correlated with BOD. DO was negatively correlated with BOD, total N, orthophosphate, total P, Zn and Fe. BOD was positively correlated with the different N fractions, orthophosphate, Zn and Fe. The different N fractions were positively correlated with each other as well as to P, Zn and Fe. The level of P was positively correlated with Zn and Fe. The levels of Zn and Fe were positively correlated with DO, BOD, the different N fractions and P.

3.2. Sediment analysis

The sediment taken from the selected sites was in general moderately alkaline (pH>8) and ranged from 8.15 at Site II to 9.0 at Sites I and IV (data not show). The levels of salinity (estimated as EC), Cl^-, SO_4^{2-}, Na^+, K^+ and Mg^{2+} in the sediment were in accordance with their levels in the sampled water with the highest levels (55.50 mmhos/cm, 69.20 g/kg, 22.74 g/kg, 11.16 g/kg, 0.95 g/kg and 5.92 g/kg respectively) at Site IV and the lowest values (1.40 mmhos/cm, 1.10 g/kg, 0.65 g/kg, 1.05 g/kg, 0.13g/kg and 0.12 g/kg respectively) at Site V (Table 3). Total N was comparable in the five sites with an average of 0.65% dry weight. Total P and OM content were higher at Sites I and V with an average of 0.45% dry weight and 9% dry weight respectively than the other sites (an average of 0.24% dry weight and 4.47% dry weight respectively). The levels of calcium carbonate and bicarbonate anion were comparable at the five sites with an average of 9.66% and 0.25 g/kg respectively (data not show).

3.3. Algal growth

Eight algal species were encountered at the selected sites. They were *S. platensis*, *Microcystis aeruginosa* (*M. aeruginosa*), *Oscillatoria agardhii* (*O. agardhii*) (Cyanophytes), *Chlorella vulgaris* (*C. vulgaris*), *Mougeotia scalaris* (*M. scalaris*), *Ulva lactuca* (*U. lactuca*), *Cladophora albida* (*C. albida*) and *D. salina* (Chlorophytes). *S. platensis* and *C. vulgaris* alternated dominance of water at Site I. Growth of *S. platensis* was very poor in the period from January to May, but increased exponentially reaching a peak in July and then declined again to moderate levels from September to November (Table 4). By contrast, growth of *C. vulgaris* was relatively high from January to March and declined to very low levels in September. *O. agardhii* and *M. scalaris* dominated water at Site II, with a succession pattern similar to that exhibited by *S. platensis* and *C. vulgaris* at Site I. *O. agardhii* dominated Site II in

Table 2

Correlation coefficients between the different characteristics of water samples at the selected sites.

	Temp	pH	Salin	COD	DO	BOD	Amm	Nitrite	Nitrate	Total N	Pi	Total P	Zn
PH	0.542**												
Salin	0.070	-0.111											
COD	0.121	-0.127	0.874**										
DO	-0.324	-0.271	-0.408*	-0.313									
BOD	0.209	0.234	0.438*	0.381*	-0.862**								
Amm	-0.062	0.325	0.172	0.221	-0.257	0.552**							
Nitrite	-0.201	0.068	0.134	0.173	-0.295	0.501**	0.796**						
Nitrate	0.059	0.241	-0.093	0.043	-0.337	0.603**	0.784**	0.659**					
Total N	-0.141	0.139	0.241	0.295	-0.374*	0.447*	0.601**	0.650**	0.622**				
Pi	0.405*	0.533**	-0.082	0.023	-0.485**	0.429*	0.435*	0.293	0.549**	0.350			
Total P	0.570**	0.371*	-0.152	-0.104	-0.555**	0.308	-0.126	-0.134	0.187	-0.001	0.667**		
Zn	0.037	0.258	-0.170	-0.156	-0.486**	0.571**	0.524**	0.496**	0.736**	0.385*	0.687**	0.389*	
Fe	0.130	0.450*	0.138	0.046	-0.533**	0.713**	0.734**	0.575**	0.743**	0.425*	0.647**	0.247	0.845**

Amm: Ammonium; Pi: Orthophosphate. $^*P \leqslant 0.05$, $^{**}P \leqslant 0.01$.

Table 3

Physicochemical properties of sediment at the different sites of study.

Site	EC (mmohs/cm)	Total N (% DW)	Total P (% DW)	OM (% DW)	Cl^- (g/kg)	SO_4^{2-} (g/kg)	Ca^{2+} (g/kg)	Mg^{2+} (g/kg)	Na^+ (g/kg)	K^+ (g/kg)
I	6.80±0.70	0.63±0.07	0.420±0.050	8.05±0.90	6.42±0.64	5.88±0.60	0.600±0.070	1.33±0.14	5.69±0.66	0.48±0.05
II	55.50±6.70	0.68±0.05	0.260±0.031	3.79±0.42	34.98±4.20	6.80±0.72	0.810±0.091	2.29±0.40	7.57±0.53	0.67±0.10
III	35.70±3.80	0.62±0.06	0.230±0.020	4.38±0.50	31.07±3.50	7.90±0.66	0.210±0.030	0.49±0.03	2.62±0.30	0.57±0.06
IV	53.28±5.80	0.69±0.07	0.250±0.030	5.24±0.55	69.20±7.30	22.74±2.50	1.180±0.200	5.92±0.55	11.16±1.50	0.95±0.10
V	1.40±0.16	0.64±0.06	0.490±0.050	10.08±1.40	1.10±0.14	0.65±0.07	0.120±0.020	0.12±0.01	1.05±0.15	0.13±0.01

Values are mean±SE, n=4. DW: Dry weight.

summer with a peak in July and was replaced by massive growth of *M. scalaris* from winter to spring with a peak in March. *C. albida* dominated Site III all over the year with particularly from summer to autumn. *D. salina* and *M. aeruginosa* dominated Site IV, with the former species flourishing during summer and the latter specie during autumn. *U. lactuca* dominated Site V particularly during summer.

Table 5 reveals that growth of the encountered algal species was determined by a variety of water characteristics, which differed from one species to the other. Growth of *S. platensis* was positively correlated with water temperature, turbidity, pH, salinity and P, but negatively correlated with N. By contrast, growth of *C. vulgaris* was negatively correlated with temperature, turbidity, pH, salinity, COD, BOD, P and Fe but positively correlated with DO and nitrite. Growth of *O. agardhii* was positively correlated with temperature, turbidity, pH, COD, P, Zn and Fe, but negatively correlated with BOD, ammonium, nitrite and total N. Growth of *M. scalaris* was negatively correlated with temperature, turbidity, pH, salinity, COD, P, Zn and Fe, but positively correlated with DO. Growth of *C. albida* was positively correlated with temperature, pH, COD, BOD and P, but negatively correlated with DO, nitrate, Zn and Fe. Growth of *D. salina* was positively correlated with temperature, turbidity, COD, BOD, ammonium and P, but negatively correlated with DO, total N and Fe. Growth of *M. aeruginosa* was positively correlated with temperature, turbidity, P and Zn, but negatively correlated with salinity, nitrite and Fe. Growth of *U. lactuca* was positively correlated with temperature, pH, salinity, but negatively correlated with Fe.

3.4. Chemical composition of algae

Table 6 presents the chemical composition of the algal species. The contents of protein and total N were relatively high in *S. platensis*, *O. agardhii*, *M. aeruginosa* and *C. vulgaris* with an average of 20.5% and 5.5% respectively. They were moderate in *M. scalaris* (15.000% and 3.100% respectively) and low in *C. albida*, *U. lactuca* and *D. salina* with an average of 11.1% and 1.7% respectively. The carbohydrate content was high in *C. albida* and *U. lactuca* with an average of 14.5%, and low in the other species with an average of 8%. Chlorophyll a was higher in *S. platensis*, *O. agardhii*, *M. aeruginosa* and *C. vulgaris* with an average of 1% than in *M. scalaris*, *C. albida*, *U. lactuca* and *D. salina* with an average of 0.5%. Chlorophyll b was higher in *C. vulgaris* and *U. lactuca* (0.43%) than in *C. albida*, *D. salina* and *M. scalaris* (0.22%). Phosphorus content was relatively high in *S. platensis*, *O. agardhii*, *M. aeruginosa*, *C. vulgaris* and *M. scalaris* with an average of 0.65% and low in *C. albida*, *U. lactuca* and *D. salina* with an average of 0.21%. The contents of ash and K were relatively high in *C. albida*, *D. salina* and *M. scalaris* with an average of 17.7% and 1.7% respectively and low in *S. platensis*, *O. agardhii*, *M. aeruginosa*, *C. vulgaris* and *U. lactuca* with an average of 8.2% and 1% respectively. The OM and OC contents were comparable in the eight species with an average of 34.2% and 20% respectively. The comparable OC content in the different species along with the variable N concentration led to marked variation ¡n the C/N ratio. This ratio was high in *C. albida* and *D. salina* with an average of 15.7, moderate in *U. lactuca* and *M. scalaris* with an average of 9.7 and low in *S. platensis*, *O. agardhii*,

Table 4

Biomass (fresh weight per unit area or unit volume) of the blooming algal species taken bimonthly from the selected sites.

Algal biomass	Site	Period					
		Jan	Mar	May	Jul	Sep	Nov
S. platensis (g/L)	I	0.002±0.000	0.005±0.001	0.53±0.06	125.60±14.00	36.400±4.200	31.40±3.60
C. vulgaris (g/L)	I	32.200±3.300	48.740±5.100	3.31±0.35	0.46±0.05	0.003±0.000	2.76±0.30
O. agardhii (g/m^2)	II	12.300±1.400	19.900±2.100	198.80±20.30	650.00±66.80	420.500±44.000	116.60±12.50
M. scalaris (g/m^2)	II	844.000±88.000	2888.000±210.000	1488.00±150.00	18.00±2.00	0.300±0.100	-
C. albida (kg/m^2)	III	3.000±0.230	2.200±0.320	11.10±1.20	13.50±1.40	15.500±1.600	9.50±1.10
D. salina (g/L)	IV	0.150±0.010	2.080±0.200	11.60±1.50	26.10±2.90	22.500±2.600	14.30±1.65
M. aeruginosa (g/L)	IV	-	-	0.60±0.04	2.80±0.30	28.000±4.200	11.00±1.50
U. lactuca (kg/m^2)	V	-	1.200±0.100	7.20±0.90	4.30±1.50	0.300±0.040	-

Values are mean±SE, n=4.

Table 5

Correlation coefficients between algal biomass and water characteristics at the sites of study.

Characteristics	*S. platensis*	*C. vulgaris*	*O. agardhii*	*M. scalaris*	*C. albida*	*D. salina*	*M. aeruginosa*	*U. lactuca*
Temp	0.674*	-0.708*	0.779*	-0.364*	0.829*	0.873*	0.454*	0.380*
pH	0.708*	-0.746*	0.350*	-0.849*	0.954*	0.243	-0.196	0.725*
Salinity	0.729*	-0.786*	0.168	-0.613*	0.060	0.260	-0.414*	0.609*
COD	-0.209	-0.652*	0.434*	-0.963*	0.485*	0.571*	0.266	0.128
DO	-0.073	0.622*	-0.136	0.719*	-0.712*	-0.587*	-0.203	0.044
BOD	-0.134	-0.429*	-0.454*	-0.304	0.564*	0.573*	0.099	-0.005
Amm	-0.359*	-0.246	-0.675*	0.116	-0.326	0.774*	0.240	-0.077
Nitrite	-0.692*	0.507*	-0.597*	-0.172	0.033	0.260	-0.477*	-0.213
Nitrate	-0.267	-0.179	-0.143	-0.182	-0.046	0.200	0.139	-0.276
Total N	-0.529*	0.329	-0.364*	-0.235	0.349	-0.641*	-0.207	0.163
Pi	0.551*	-0.856*	0.672*	-0.761*	0.362*	0.795*	0.604*	0.224
Total P	0.767*	-0.800*	0.785*	-0.733*	0.874*	0.952*	0.501*	-0.062
Zn	-0.086	-0.146	0.443*	-0.622*	-0.875*	0.059	0.469*	0.217
Fe	0.185	-0.379*	0.486*	-0.730*	-0.196	-0.686*	-0.482*	-0.736*

Amm: Ammonium; Pi: Orthophosphate. *$P \leqslant 0.05$.

Table 6
Chemical analysis of the bloom forming algal species encountered at the selected sites.

Constituent	*S. platensis*	*O. agardhii*	*M. aeruginosa*	*C. vulgaris*	*C. albida*	*U. lactuca*	*D. salina*	*M. scalaris*
Protein (%)	22.200±2.400	19.40±2.00	21.00±3.20	19.25±2.10	9.73±1.10	11.83±1.00	11.800±1.200	15.000±1.900
carbohydrate (%)	7.100±0.800	6.90±0.71	6.10±0.60	8.80±0.90	11.50±1.20	17.56±1.00	9.800±1.100	9.000±0.710
Chlorophyll a (%)	1.320±0.120	0.96±0.12	0.90±0.10	0.85±0.08	0.37±0.04	0.67±0.10	0.400±0.041	0.600±0.050
Chlorophyll b (%)				0.42±0.04	0.17±0.02	0.45±0.10	0.200±0.023	0.300±0.030
Total N (%)	5.700±0.550	5.23±0.52	5.80±0.50	5.17±0.52	1.19±0.21	2.40±0.19	1.300±0.120	3.100±0.320
Total P (%)	0.670±0.520	0.75±0.10	0.62±0.10	0.62±0.07	0.19±0.02	0.23±0.20	0.200±0.003	0.600±0.060
K (%)	1.200±0.140	0.88±0.11	0.90±0.10	0.81±0.08	1.80±0.12	1.25±0.20	1.680±0.210	1.400±0.050
Ash (%)	8.800±0.340	7.20±0.08	7.10±0.10	7.91±0.07	22.20±2.30	9.82±1.20	16.000±0.900	15.000±1.400
OM (%)	35.800±3.400	35.40±3.60	35.30±4.10	35.09±4.00	32.80±3.50	35.11±3.00	31.000±1.600	33.000±2.600
OC (%)	20.750±2.100	20.50±2.20	20.40±2.70	20.50±2.20	19.50±2.10	20.31±2.00	18.900±1.400	19.000±1.700
C/N ratio	3.640±0.400	3.90±0.40	3.50±0.20	3.90±0.36	16.40±1.50	8.46±0.80	15.000±1.800	11.000±1.200
Zn (mg/g)	0.170±0.020	0.07±0.01	0.11±0.12	0.09±0.01	0.06±0.00	0.04±0.01	0.070±0.100	0.070±0.010
Cu (mg/g)	0.010±0.001	0.03±0.01	0.02±0.00	0.02±0.00	0.02±0.00	0.01±0.00	0.020±0.000	0.020±0.010
Pb (mg/g)	0.010±0.001	0.01±0.00	0.01±0.00	0.01±0.00	0.02±0.00	0.01±0.00	0.020±0.000	0.020±0.020
Fe (mg/g)	1.680±0.150	0.47±0.04	0.61±0.05	0.47±0.05	2.28±0.23	0.63±0.00	2.300±0.340	1.200±0.160
Mn (mg/g)	0.040±0.010	0.07±0.01	0.06±0.01	0.11±0.02	1.52±0.13	0.28±0.00	1.600±0.150	0.600±0.050

Values are the mean±SE, *n*=4. Constituents were calculated on dry weight basis.

M. aeruginosa and *C. vulgaris* with an average of 3.7.

Zinc content was the highest in *S. platensis* with an average of 0.17 mg/g, moderate in *M. aeruginosa* and *C. vulgaris* with an average of 0.10 mg/g and low in *O. agardhii, C. albida, U. lactuca, D. salina* and *M. scalaris* with an average of 0.06 mg/g. Mn content was high in *C. albida* and *D. salina* with an average of 1.55 mg/g, moderate in *M. scalaris* and *U. lactuca* with an average of 0.44 mg/g and low in *S. platensis, O. agardhii, M. aeruginosa* and *C. vulgaris* with an average of 0.07 mg/g. The contents of Cu and Pb were very low and comparable in the eight species with an average of 0.019 and 0.014 mg/g dry weight respectively. Fe content was high in *D. salina* and *C. albida* with an average of 2.29 mg/g , moderate in *S. platensis* and *M. scalaris* with an average of 1.4 mg/g and low in *O. agardhii, M. aeruginosa C. vulgaris* and *U. lactuca* with an average of 0.55 mg/g.

4. Discussion

Algal growth is the outcome of the interaction between the organism and its habitat. Among the environmental factors limiting the phytoplankton community, temperature is the most important[20]. Growth of most of the algal species encountered in the present investigation showed positive correlation with temperature and flourish during summer. However, *C. vulgaris* and *M. scalaris* were exceptional that they showed negative correlation with temperature and flourish during winter. This temperature response might partially explain the succession observed between *S. platensis* and *C. vulgaris* at Site I, as well as between *O. agardhii* and *M. scalaris* at Site II and *D. salina* and *M. aeruginosa* at Site IV. In agreement with our findings, cyanobacteria have been reported to appear in summer and green algae in spring[21].

The limited seasonal variation in water characteristics, except temperature, might be due to the mild weather of the study area and a continuous supply of pollutants. Waters at some sites would randomly modify water properties over the season and maximize the local variation in water parameters between sites.

The sharp local variation in DO, COD and BOD can be related to the level of organic pollution of water. Sewage discharge is considered the major component of water pollution, which contributes to increased oxygen demand and nutrient loading to water bodies. It would promote noxious algal blooming and lead to a fragile aquatic ecosystem[22]. The limited but significant seasonal fluctuation in DO, with relatively high values during winter and low values during summer, might be due to the seasonal variation in water temperature. Similar results have been reported[23]. The negative correlation found in the present work between DO and BOD, COD, nitrite-N, orthophosphate, nitrate-N and ammonia-N, respectively, might signify that photosynthesis of aquatic biota is the main source of DO. It has been suggested that the decreasing DO level of water, especially if associated with high levels of BOD and COD, can be taken as an indicator of organic pollutants and/or toxicants[24].

The positive correlation observed between the nitrogen fractions and BOD, Fe, Mn and P, respectively, may be related to the pollution status of water, activity of biogeochemical cycling and bioconsumption of mineral nitrogen. In natural habitats, nitrate and ammonium represent the main source of nitrogen for algal growth, but in highly polluted waters, organic nitrogen may become increasingly important[25]. In this respect, a close relationship has been reported between pollution level of water and nitrite/ammonia[26]. In addition, the level of nitrite was negatively correlated with DO of water and associated with collapse of algal blooms[27]. This might be due to the fact that nitrate can take the role of O_2 as an electron acceptor under conditions of low O_2 tension, thereby reduced the nitrite which is a toxic product. Thus, accumulation of nitrite can be considered as an indication of oxygen deficiency and water pollution.

The high local variation in orthophosphate levels of water might be due to variation in the income of pollutants from domestic and agricultural discharges, which would be particularly effective in shallow waters. In this respect, low DO might permit the release of nutrients bound in bottom sediment, including various forms of phosphorus[28]. Phytoplankton growth is generally controlled by availability of the potential growth-limiting nutrients, in particular phosphorus.

The marked local variation in heavy metals (Zn and Fe) concentrations is related to variation in depth and pollution level

of water. Heavy metals content was positively correlated with orthophosphates. It has been demonstrated that shallow water, if accompanied with waste water discharge, registered the highest levels of nutrients and dissolved heavy metals[29].

The matched pH values and salinity levels of sediment and water at the different sites means equilibrium between these two phases. Nutrient enrichment especially with N and P through high loads of sewage and agricultural discharges might contribute to the high nutrient content of sediment at Site I. The high levels of total N, total P, OM and calcium carbonate at Site II could be related to the high growth of the hydrophytes *Zygophyllum* sp., *Ruppia maritma* and *U. lactuca*, which would lead to an increase in OM content of sediment upon death and decay, and the industrial and domestic sewage discharged into the Lake Manzala. The excessive salinity of Site IV is the outcome of the nature of the site (a shallow salt marsh) with no fresh water supplement. On the other hand, the low levels of salinity and OM of sediment at Sites II and III, might be due to the continuous supply of fresh water mixed with sewage discharges commonly observed at these sites.

The standing crop of blooming algae is governed by a complex interplay of environmental conditions. Proliferation of *S. platensis* and *C. vulgaris*, at Site I (a site of stagnant turbid water) may be due to exposure to pollutants, mainly untreated sewage and agricultural and industrial drainage. This would result in eutrophication of water and partial depletion of DO, thus creating favorable conditions for bloom formation. *Spirulina* species have been reported to grow well in polluted habitats and under low DO[30].

At Site II, the luxurious growth and succession between *O. agardhii* and *M. scalaris* in summer and winter respectively can be related to the level of DO which was low in summer and high in winter. This in addition to the effluent of sewage and fresh water which would result in very low salinity. In agreement with these results, *Oscillatoria* spp. have been reported to withstand or even tolerate habitats with low oxygen tension, particularly if amended with agricultural and domestic sewage[31]. The succession between *S. platensis* and *C. vulgaris* at Site I and between *O. agardhii* and *M. scalaris* at Site II may be partially related to the changes in water temperature and its consequences on water characteristics, especially DO. In this respect, *C. vulgaris* was regarded as the most successful alga in waste water oxidation ponds[32].

The massive growth of *C. albida* at Site III over the entire period of investigation with a peak in summer may be related to both salinity and stagnant nature of the shallow water at this site. Abundance and seasonal periodicity of *C. albida* have been reported to be influenced by water depth and stream velocity[33] as well as temperature[6]. The massive growth of *C. albida* creates a serious problem to fisheries since this leads to sheltering of several aquatic microorganisms and high consumption of DO, which increases BOD, COD and accelerates the decay of dead algae and the release of noxious odors. Expectedly, DO decreases gradually after sunset reaching a minimum around midnight, especially near the bottom. This results in mortality of young fishes and /or movement of mature fishes to the surface water and loss of biodiversity[34].

The massive growth of *D. salina* in the highly saline water (Site IV) in summer is in accordance with the fact that this microalga is a halophytic one[35]. The decrease of water salinity at this site as a result of the access of fresh water supply creates a favorable environment for growth of *M. aeruginosa* during late autumn. The high growth of *U. lactuca* at Site V during spring may be related to the supply of sewage and agricultural and industrial discharges into the marine water. It has been concluded that eutrophic stagnant water enhances the massive growth of macroalgae, and their composition/ diversity is greatly influenced by the composition of nutrients and contaminants in water system[36].

The high levels of OM, protein and minerals along with the low C/N ratio of *S. platensis* evaluate this cyanophyte for use as a bio-fertilizer and also in waste water management which has been previously suggested[31]. The moderate nutritive value and the low C/N ratio of *O. agardhii* allow the use of this alga as a food additive for animals and as a bio-fertilizer. The quick decomposition of *M. aeruginosa* in the soil, associated with its high N content, can increase soil fertility by amending the soil with nitrogen.

The high protein content along with the low content of carbohydrates and moderate mineral content of *C. vulgaris* evaluate the alga for use as food additive. In this respect, microalgae have been used as a raw material of single cell protein[37]. The alga can also be applied in agriculture as a bio-fertilizer by virtue of its high content of OM and the low C/N ratio.

The relatively low protein content and the high content of carbohydrate and ash of *C. albida* qualify the alga for use as a fodder for small fish and invertebrates, while the high ash and K contents along with the high C/N ratio evaluate the alga as a bio-fertilizer. In addition, the relatively high contents of Fe and Zn point to the ability of *C. albida* and *M. scalaris* to grow in habitats polluted with heavy metals, and to accumulate these metals, which can be exploited in phytoremediation of polluted waters. In this regard, *Cladophora* species have been reported to be the best bio-indicators of aquatic habitats contaminated by nutrients as well as by heavy metals, and possess an excellent phytoremediation potential[38].

The physico-chemical characteristics of water and sediment at the selected sites showed remarkable local variation, partially determined by the level of fresh water and sewage supply. The high levels of COD and BOD indicate marked organic pollution, which lead to water eutrophication. *S. platensis* and *O. agardhii* formed massive blooms during summer at Sites I and II respectively and were replaced by *C. vulgaris* and *M. scalaris* respectively during winter. This succession can be related the alternation of water temperature and level of DO. *C. albida* exhibited massive growth over the whole period of study at different sites, particularly Site III (a shallow fish farm) characterized by high level of organic fish manures, leading to nutrients enrichment especially with N and P. The blooming of *D. salina* at the highly saline site (Site IV), during summer and its associated with *M. aeruginosa* in late autumn can be related to fluctuation of water salinity by the access of fresh water supply during autumn. The massive growth of *U. lactuca* during spring at the marine shallow water (Site V) was due to high income of sewage and industrial runoff.

The eight dominant algal species have a promising nutritive value (protein content of 9%-22%, carbohydrate content of 6%-17%) in addition to photosynthetic pigments, macronutrients and

micronutrients. This evaluates these algae can be used as food, fodder and bio-fertilizer, since they have both high OM content and low C/N ratio.

Conflict of interest statement

We declare that we have no conflict of interest.

Acknowledgements

The authors are grateful to Prof. Dr. Mostafa M. El-Sheikh, at Tanta University for his critical revision of the manuscript and his valuable remarks.

Comments

Background

Marine macro- and microalgae including cyanobacteria are the main primary producers in the seas and oceans. Most of them are rich in proteins and active compounds. Marine cyanobacteria (blue-green algae) are well known to produced pharmaceutical compounds which could be used for the treatment of recent diseseas such as HIV virus, cancer, *etc*. Therefore, the beneficial and harmful constituents of these algae should be isolated, characterized and evaluated their toxicological and medicinal importance.

Research frontiers

The present study described the presence of massive growths of macro- and microalgae including cyanobacteria, and its relation with environmental factors prevailing in Damietta Mediterranean coasts. The study also shed some light on the chemical composition of these algae, to be potentially considered as a source for medicinal compounds.

Related reports

Algal blooms are frequent along coasts worldwide. The toxic impacts on human environmental health are well known. Pharmaceutical compounds and toxins produced by some marine species, particularly cyanobacteria were largely explored.

Innovations and breakthroughs

Many studies worldwide investigated the algal blooms in the coastal waters. Other studies revealed the biological activities of some species and isolates particularly cyanobacteria. The authors did the same investigations, hopefully to find new active compounds.

Applications

The occurrence of some algal species could be used as an bio-indicator for the pollution of the coastal water with industrial wastes and river discharges. Some species constituting these blooms, particularly the nontoxic species could be used in the soil fertilization and/or a source of pharmaceutical substances.

Peer review

The authors gathered valuable data stating the current status of Damietta Mediterranean coastal waters in terms of eutrophication and algal blooms. On the other hand, the study demonstrated that some of these algal species are rich in proteins and nutritional elements.

References

[1] Beaudeau P, Schwartz J, Levin R. Drinking water quality and hospital admissions of elderly people for gastrointestinal illness in Eastern Massachusetts, 1998-2008. *Water Res* 2014; **52**: 188-198.

[2] Selvi Dhanam D, Dhandayuthapani K. Optimization of β-carotene production by marine microalga-*Dunaliella salina*. *Int J Curr Microbiol Appl Sci* 2013; **2**: 37-43.

[3] Patiño R, Dawson D, VanLandeghem MM. Retrospective analysis of associations between water quality and toxic blooms of golden alga (*Prymnesium parvum*) in Texas reservoirs: implications for understanding dispersal mechanisms and impacts of climate change. *Harmful Algae* 2014; **33**: 1-11.

[4] Song M, Pei H, Hu W, Zhang S, Ma G, Han L, et al. Identification and characterization of a freshwater microalga *Scenedesmus* SDEC-8 for nutrient removal and biodiesel production. *Bioresour Technol* 2014; **162**: 129-135.

[5] Vincent WF, Quesada A. Cyanobacteria in high latitude lakes, rivers and seas. In: Whitton BA, editor. *Ecology of cyanobacteria II: their diversity in space and time*. Dordecht: Springer; 2012, p. 371-385.

[6] Higgins SN, Pennuto CM, Howell ET, Lewis TW, Makarewicz JC. Urban influences on *Cladophora* blooms in Lake Ontario. *J Great Lakes Res* 2012; **38**: 116-123.

[7] Ouedraogo HG, Kouanda S, Bationo F, Doulougou B, Ouedraogo/ Nikiema L, Lanou H, et al. Effects of spirulina supplementation on selected anthropometric, biochemical, and hematological parameters of HIV-infected adults in Ouagadougou, Burkina Faso. *Int J Biol Chem Sci* 2013; **7**: 607-617.

[8] Azabji-Kenfack M, Dikosso SE, Loni EG, Onana EA, Sobngwi E, Gbaguidi E, et al. Potential of *Spirulina platensis* as a nutritional supplement in malnourished HIV-infected adults in sub-saharan Africa: a randomized, single-blind study. *Nutr Metab Insights* 2011; **4**: 29-37.

[9] Bermejo P, Piñero E, Villar AM. Iron-chelating ability and antioxidant properties of phycocyanin isolated from a protean extract of *Spirulina platensis*. *Food Chem* 2008; **110**: 436-445.

[10] Abd El-Aty AM, Mohamed AA, Samhan FA. *In vitro* antioxidant and antibacterial activities of two fresh water cyanobacterial species, *Oscillatoria agardhiiand* and *Anabaena sphaerica*. *J Appl Pharm Sci* 2014; **4**: 069-075.

[11] Cai T, Park SY, Li Y. Nutrient recovery from wastewater streams by

microalgae: status and prospects. *Renew Sust Energ Rev* 2013; **19**: 360-369.

[12] Jackson ML. *Soil chemical analysis*. New Jersey: Prentice-Hall Inc.; 1973, p. 574.

[13] American Public Health Association. *Standard methods for examination of water and wastewater*. 22nd ed. Washington D.C.: American Public Health Association; 2012, p. 116.

[14] Sladká A, Sládeček V. *A guide of organisms from wastewater plants*. Prague: State Agricultural Press; 1985.

[15] Rott E. Primary productivity and activity coefficients of the phytoplankton of a mesotrophic soft-water lake (Piburger See, Tirol, Austria). *Int Revue Ges Hydrobiol Hydrogr* 1981; **66**: 1-27.

[16] Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with Folin phenol reagent. *J Biol Chem* 1951; **193**: 265-275.

[17] Herbert D, Phipps PJ, Strange RE. Chemical analysis of microbial cells. In: Norris JR, Ribbons DW, editors. *Methods in microbiology*. New York: Academic Press; 1971, p. 209-344.

[18] Talling JF, Driver D. Some problems in the estimation of chlorophyll-a in phytoplankton. Proceedings of the Conference of Primary Productivity Measurement, Marine and Freshwater; 1961; Hawaii, USA. Hawaii: United States Atomic Energy Commission; 1963, p. 142-146.

[19] Allen SE, Grimshaw HM, Rowland AP. Chemical analysis. In: Moore PD, Chapman SB, editors. *Methods in plant ecology*. Oxford: Blackwell Scientific Publications; 1986, p. 285-343.

[20] Toseland A, Daines SJ, Clark JR, Kirkham A, Strauss J, Uhlig C, et al. The impact of temperature on marine phytoplankton resource allocation and metabolism. *Nat Clim Change* 2013; **3**: 979-984.

[21] Zhang Y, Yin Y, Wang M, Liu X. Effect of phytoplankton community composition and cell size on absorption properties in eutrophic shallow lakes: field and experimental evidence. *Opt Express* 2012; **20**: 11882-11898.

[22] Igbinosa EO, Okoh AI. Impact of discharge wastewater effluents on the physico-chemical qualities of a receiving watershed in a typical rural community. *Int J Environ Sci Tech* 2009; **6**: 175-182.

[23] el-Nagar ME, Shaaban-Dessouki SA, Abdel-Hamid MI, Aly EM. Studies on the phytoplankton populations and physico-chemical conditions of treated sewage discharged into Lake Manzala in Egypt. *New Microbiol* 1998; **21**: 183-196.

[24] Waziri M, Ogugbuaja VO. Interrelationships between physicochemical water pollution indicators: a case study of River Yobe-Nigeria. *Am J Sci Ind Res* 2010; **1**: 76-80.

[25] Camargo JA, Alonso A. Inorganic nitrogen pollution in aquatic ecosystems: causes and consequences. Encyclopedia of Earth; 2007. [Online] Available from: http://www.eoearth.org/view/article/153841 [Accessed on 20th September, 2014]

[26] Madkour FF. Ecological studies on the phytoplankton of the Suez Canal [dissertation]. Ismaïlia: Suez Canal University; 2000, p. 254.

[27] Mullineaux CW. The thylakoid membranes of cyanobacteria: structure, dynamics and function. *Aust J Plant Physiol* 1999; **26**: 671-677.

[28] Correll DL. Phosphorus: a rate-limiting nutrient in surface waters. *Poult Sci* 1999; **78**: 674-682.

[29] Valipour A, Raman VK, Motallebi P. Application of shallow pond system using water hyacinth for domestic wastewater treatment in the presence of high total dissolved solids (TDS) and heavy metal salts. *Environ Eng Manag J* 2010; **9**: 853-860.

[30] Magro CD, Deon MC, De Rossi A, Reinehr CO, Hemkemeier M, Colla LM. Chromium (VI) biosorption and removal of chemical oxygen demand by *Spirulina platensis* from wastewater-supplemented culture medium. *J Environ Sci Health A Tox Hazard Subst Environ Eng* 2012; **47**: 1818-1824.

[31] Das M, Panda T. Water quality and phytoplankton population in sewage fed river of Mahanadi, Orissa, India. *J Life Sci* 2010; **14**: 81-85.

[32] Deyab MA, Nemat Aalla MM, El-Adl MF. Phytoplankton diversity in some ponds at New Damietta-Egypt. *Egypt J Phycol* 2002; **3**: 1-15.

[33] Hu BF, Feng J, Xie SL. Occurrence of epiphytic algae on three stream macroalgae in xin'an spring, North China. *Acta Hydrobiol Sin* 2012; **36**: 291-298.

[34] Deyab MA, Khedr AA, El-Naggar MA. Phytoplankton distribution in relation to environmental factors along the Suez Canal and the Red Sea Coast of Egypt. *Algol Stud* 2004; **112**: 123-140.

[35] Borowitzka MA, Siva CJ. The taxonomy of the genus *Dunaliella* (Chlorophyta, Dunaliellales) with emphasis on the marine and halophilic species. *J Appl Phycol* 2007; **19**: 567-590.

[36] Renuka N, Sood A, Prasanna R, Ahluwalia AS. Influence of seasonal variation in water quality on the microalgal diversity of sewage wastewater. *S Afr J Bot* 2014; **90**: 137-145.

[37] Mahboob S, Rauf A, Ashraf M, Sultana T, Sultana S, Jabeen F, et al. High-density growth and crude protein productivity of a thermotolerant *Chlorella vulgaris*: production kinetics and thermodynamics. *Aquacult Int* 2012; **20**: 455-466.

[38] Bhatnagar S, Kumari R. Bioremediation: a sustainable tool for environmental management-a review. *Annu Rev Res Biol* 2013; **3**: 974-993.